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COMBUSTION OF SYNCRUDE-COKE IN PYROFLOW PILOT PLANT, JUNE 1981

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ABSTRACT

Eighteen tons of Syncrude coke was burnt in the PYROFLOW furnace in Hans Ahlström Laboratory. Gotland limestone was used to capture SO_2 as $CaSO_4$. The test objectives were to examine the capability of the PYROFLOW furnace to burn the mentioned fuel, performance of furnace and emission characteristics.

Trials were made in varying temperatures, 820 - 950°C. The temperature level which was found to give the best operating conditions was c. 900°C. Combustion capacity varied between 1.01 MW and 1.95 MW.

Combustion efficiency was 95.8 - 98.9 % based on higher heating value. Major loss was caused by unburned carbon in ash. Increasing temperature was noticed to give better combustion efficiency. Same effect has also increasing secondary air and excess air.

SO_2-emissions were controlled by limestone; 89.7 - 93.7 % SO_2 retention was achieved with Ca/S-ratio 1.72 - 2.09 mol/mol. Baghouse ash recirculation improves SO_2 capture in higher temperatures.

NO_x-emissions were 0.114 - 0.741 g NO_2/MJHHV. Increasing secondary air was found to give lower NO_x-level.

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1. INTRODUCTION

Syncrude coke is a byproduct produced in large quantities by the Syncrude oil sands extraction plant at Fort McMurray, Alberta, Canada. It has high specific energy content, being high in carbon content and low in ash. It is, however, considered to be a difficult fuel because it is low in volatiles and high in sulphur. Carbon in the coke is graphitic or other relatively inert carbon forms.

Recirculating fluidized bed combustor gives a potential way to burn this fuel and to handle emission difficulties, too.

From the viewpoint of Hans Ahlström Laboratory the trials with Syncrude coke belong to a larger test program of various North American coals. Eighteen tons of Syncrude coke was burned with the pilot plant FBC-800 in Hans Ahlström Laboratory. Gotland limestone was used to capture SO_2 as $CaSO_4$.

According to the emission guidelines of the Canadian Ministery of the Environment /1/, Syncrude coke belongs to the group of solid fuels which theoretical SO_2-emission is over 2.58 g SO_2/MJ_{HHV}. Thus it requires 90 per cent removal of SO_2 as minimum. NO_x-emission should not exceed 0.258 g NO_2/MJ HHV.

2. OBJECTIVES OF THE TRIALS

The most important objectives of the test runs were to find the optimum run conditions in which the best combustion efficiency and minimum pollutant emissions could be achieved. Limestone was used to control SO_2-emission and the effects of different input variables to minimize limestone consumption were examined.

The following input variables were selected; bed temperature, fuel feed rate (load), ash recirculation. The important output variables were: unburned material in flue gas and ash, SO_2 capture, NO_x-emission.

3. EQUIPMENT

The fluidized bed combustor used in trials has a 0.8 m diameter. A high temperature cyclone separates solids from offgas and recirculates then back into the bed through valveless seal, see Fig 1.

Freeboard temperature is controlled by bayonet cooling tubes hanging from the top of reactor. The length of the tubes inside the furnace is adjustable. Bed temperature is controlled by an immersed water tube in bed.

Flue gas goes from cyclone into a boiler. The boiler consists of two parts divided by a wall. The first part has four countercurrent water tubes, the second one has two parallel current tubes.

Flue ash is separated in a baghouse from offgas. There is still a venturi scrubber on line after the baghouse. The baghouse may be passed if needed.

It is possible to recirculate a given amount of fly ash from the baghouse back to the reactor.

The continuous offgas analyzing equipment on line after the cyclone is listed in Tab 1.

Tab. 1. Gas analyzers on FBC-800 in HA Laboratory

NO/NO_x	Beckman, Model 951
SO_2	Hartman & Braun, Uras 7 N
CO	- " -
O_2 (in dry gas)	Taylor Servomex, Type OA 272
O_2 (in wet gas)	Westinghouse, Model 218

Flow rates, temperatures, pressures, emission measurements, etc. were collected by Digitals Minc-11 computer. Minc was also used in balance calculations afterwards. Most of the measurements were also plotted by recorders and indicated on a control panel.

Coal was fed by a screw and limestone by a rotary feeder. Material was weighed before putting it into bins. Average feed rate was calculated on the basis of time records of weighing.

Ash from coarse ash removal, boiler ash removal and baghouse ash were each gathered in a container, which was weighed with time records.

4. SAMPLING AND ANALYSES

Following samples were taken and analyzed with regard to given properties:

a) coal feed; one sample of each cast load (c. 300 kg) of coke:, dry solids, ash, sulphur, screen analysis, ultimate analysis and HHV of overall sample

b) limestone; one sample per three hours, dry solids, ignition loss at 900°C, screen analysis

c) coarse ash; one sample per two hours, mixed for a run; unburned C, Ca, S

d) boiler ash; once in two hours, C, Ca, S

e) baghouse ash; once in two hours; C, Ca, S

f) Venturi water; once per hour, analyzed only the maximum load samples when the baghouse was bypassed; C, solids

5. COARSE OF TRIALS

Eight test runs were made. The time under stable conditions was from seven to ten hours in each run; one run took 13 hours. Gotland limestone was used as SO_2-sorbent and feed rate was controlled so that desired SO_2- concentration in flue gas was achieved. This SO_2-level was calculated to give at least 90 per cent SO_2 retention.

June 1, 1981, Run 1

The reactor was heated up with heavy oil on Monday morning. Coke feed was started at 4.30 p.m. which time is considered to be a beginning of the first run. No limestone was fed into reactor. The main objective of the run was to get SO_2-emission level without any auxiliary sorbent than the own ash of coke. The input parameters were following: bed temperature 885°C, O_2 in wet flue gas was 8.4 %. Theoretical SO_2 emission was 4.34 g SO_2/MJHHV giving 3600 ppm concentration for measured O_2 content. The measured SO_2 content was 3114 ppm which means 13.5 % SO_2 removal due to own ash of coke. NO_x emission was rather high being 0.741 g NO_2/MJHHV. Fly ash was not recirculated.

June 2, 1981, Run 2

Limestone feed begun at 5.04. The limestone feeder got out of order in the forenoon and it had to be repaired. Stable running conditions were achieved by noon. The run parameters were: bed temperature 892°C, sup. gas vel. 3.7 m/s, combustion capacity 1.40 MW (HHV), O_2 in wet flue gas 3.2 %. Ca/S-ratio as low as 1.82 mol/mol, Gotland limestone seemed to have quite good reactivity. NO_x-level fell down strongly, 0.183 g NO_2/MJHHV, which meets the given emission guidelines 0.258 g NO_2/MJHHV.

June 3, 1981, Run 3

The object of this run was to study the effect of high temperature on burning efficiency and limestone utilization. Temperature level

was raised up to 950°C and other running conditions were as follows: combustion capacity 1.64 MW, O_2 2.6 %.

There were some difficulties in achieving the desired temperature level. The limiting device was the flue gas fan.

If one compares the results of this run with the results of run 2, there is no improvement in combustion efficiency. However, there is a slight increase in SO_2-retention with nearly the same Ca/S-ratio.

June 3, 1981, Run 4

This run was made with a low combustion capacity, 1.01 MW, bed temperature was 820°C, O_2 content in wet flue gas was 2.9 %. SO_2 capture 90.6 % was achieved with a higher Ca/S-ratio, 1.97 mol/mol. NO_x-emission stayed at quite a low level, 0.172 $gNO_2/MJHHV$ due to low temperature.

June 4, 1981, Run 5

Baghouse ash was recirculated so that 7.5 % of the outcoming ash was pneumatically conveyed back into the furnace. Other run parameters were kept as unchanged as possible. Ash recirculation brought improvement in combustion efficiency by c. 1 %. Better limestone utilization was not noticed. SO_2 retention was 91.5 % with a Ca/S-ratio of 2.06 mol/mol. NO_x-emission increased undesirably high 0.331 g/MJ. Dust concentration in fluegas increased strongly. Calculated value in previous run was 14.7 g/Nm^3 before the boiler; it was 74.2 g/Nm^3 when recirculating. This might have the reason to higher gas temperatures in the boiler during recirculation.

June 4, 1981, Run 6

Ash recirculation rate was kept unchanged. Bed temperature was increased up to 900°C. This temperature gave extremely good result in limestone utilization; 90.2 % SO_2 capture was achieved by as low

a Ca/S-ratio as 1.72 mol/mol. Also there was slight improvement in combustion efficiency.

June 8, 1981, Run 7

Baghouse ash recirculation was stopped and the run was performed with temperature level 840°C. Combustion capacity was quite low, 1.14 MW. O_2 content in wet offgas 5.4 %. Special attention was payed to NO_x concentration in flue gas. The main reason to high NO_x levels in some of the previous runs was found to be low secondary air amount.

June 8, 1981, Run 8

Run was made with full combustion capacity, 1.95 MW, in temperature 890°C. The capacity of the baghouse filters was too small for big dust loads of this kind. Because of this it was bypassed. The samples of venturi water were taken and analyzed in order to estimate fly ash amounts and unburned carbon in fly ash. Other running parameters were: 53.6 %, O_2 in wet gas 5.0 %. Combustion efficiency was 98.9 % and SO_2 retention 89.7 % was achieved with Ca/S-ratio 1.87 mol/mol. NO_x level was low, 166 ppm, which means 0.114 g NO_2/MJHHV.

6. RESULTS

6.1. Coke characteristics

All eight runs were performed with Syncrude coke. The analysis of coke is presented in Tab 2.

Tab. 2. Syncrude coke analysis

Moisture	2.58 wt-%
Volatile matter	5.44 "
Ultimate; wt-% in dry solids	
Ash	6.59
C	81.7
H	1.79
N	1.52
S	6.55
O (as difference)	1.85
	Σ 100.00
HHV of dry solids	31 260 kJ/kg

Sulphur and ash content were analyzed for each stabilized run period from overall sample of coke. Sulphur content varied very little, from 6.74 to 6.82 per cent. Ash content varied from 6.51 to 6.82 per cent.

The size distributions of coke in each run are presented in App. 1 A and B. According to App. 1 A and B, 50 wt-% of material is smaller than 0.14 - 0.15 mm in average.

6.2. Limestone characteristics

Gotland limestone was used to capture SO_2 as $CaSO_3$. Chemical composition (analysis from K. Forström Ltd + Forgy, Sweden) is presented in Tab. 3.

Tab 3. Gotland limestone characteristics

$CaCO_3$	94.8 wt-%
$MgCO_3$	1.7 "
Free SiO_2 and compounds of SiO_2, Al_2O_2 and Fe_2O_3	2.1 "
Total	98.6 "
Ignition loss (900°C; HA-Laboratory)	57.94 %

In calculations all carbonate was assumed to be $CaCO_3$. The ignition loss analysis then gives 95.66 % $CaCO_3$ content. 50 wt-% of particles were smaller than 75- 90 µm and 99.7 % smaller than 0.5 mm, see App. 2.

6.3. Process data in trials

Process data of trials is gathered in Tab 4. The average temperature in reactor varied between 817°C and 945°C. The trials were performed with following temperature levels:

- c. 820°C; two runs (no. 4,5)
- c. 840°C; one run (no. 7)
- c. 880-890°C; four runs (no. 1, 2, 6, 8)
- c. 950°C; one run (no. 3)

Temperature gradients in furnace varied between 10°C and 20°C, except in run 1 where it was 31°C, see App 3-5.

In run no. 1 no limestone was used. It was found 13.5 % SO_2 capture without sorbent. This was caused by the own ash of coke. Limestone utilization in run no. 2...8 was very good. Ca/S ratio varied between 1.72 mol/mol and 2.09 mol/mol.

Baghouse ash was recirculated in two runs (5, 6) with different temperature. Recirculation and 900°C temperature level gave a good result in regard to limestone utilization. In low temperatures

ash recirculation did not seem to have any advantage.

During the trials the NO_x-level became a problem. However, it was got within bounds easily by using more secondary air in two last runs.

6.4. Material and energy balance calculations

The process data was collected with Digital's Minc -11 process computer. Channel reading frequency was one minute. After ten minutes computer calculated mean value and scaled voltages to temperatures, flow rates etc. These ten minute sequences were printed on lineprinter and saved on diskettes, too.

Afterwards these ten minute averages were combined to averages of larger balance period by a separate program.

For material and energy balance calculation a new computer program MEB was developed. It collects a desired file from the diskette memory and picks up the values needed for balance calculations.

The material balance part of the program is general and it takes account of measured O_2 content in flue gas and analyzed carbon content in ash when calculating air requirement. Material balance also agree with measured SO_2, NO_x and CO content in flue gas as well as calcination/sulphidation reactions in SO_2 absorbtion.

The energy balance part of the program calculates energy balance from the basis of material balance and measured temperatures, cooling water flows and other quantities. It takes account of the heats of calcination/sulphidation reactions in SO_2 absorbtion. Also the losses due to unburned material are taken into concideration.

Balance sheets computed by MEB are presented in App. 6-13.

6.4.1. Combustion air

Combustion air moisture was 1.27 % (kg H_2O/kg wet air x 100). In balance calculation theoretical air requirement was solved on the basis of O_2 and CO content in flue gas and mean C content in ash. The latter was calculated by weighing the analyzed C content in bed and fly ash with measured mass flows of them.

Excess air varied between 7.3 % and 67 % which means 2.51 % and 8.37 % O_2 in wet offgas, respectively.

6.4.2. Combustion efficiency

Energy loss due to unburned carbon in ash was calculated in two different ways. In computer calculations the fly ash carbon content was assumed to be the same as in baghouse ash. The average carbon content in overall ash was calculated from the formula (1).

$$(1) \quad W_C = \frac{W_{ba}\, C_{ba} + W_{fa}\, C_{fa}}{100}$$

where: W_{ba} ≙ bottom ash of total (% of weighed ash)
W_{fa} ≙ fly ash of total (% - " -)
C_{ba} ≙ carbon content in bottom ash (anal.)
C_{fa} ≙ carbon content in fly ash (anal.)

The computer then calculated unburned carbon massflow to meet the average carbon content.

Energy loss due to unburned CO in offgas was calculated with regard to CO measurement. Energy losses and combustion efficiencies are presented in App 6 - 13. Combustion efficiencies are calculated both based on input higher heat value and carbon input.

In tab 5 heat losses due to unburned material are based on weighed ash amounts. However, reliability of ash weighing was not good in many runs.

Date		2.6.-81	2.6.-81	3.6.-81	3-4.6.-81	4.6.-81	4.6.-81	8.6.-81	9.6.-81
Time		0.30-4.30	12.12-15.00	8.11-10.04	17.28-2.05	2.30-9.00	17.00-20.15	11.33-21.30	0.00-6.28
Run		1	2	3	4	5	6	7	8
Coke feed									
origin		syncrude coke in all runs							
size(50 % smaller than)	mm	0.15	0.14	0.14	0.14	0.15	0.14	0.15	0.15
feeding rate	g/s	38.9	45.5	53.3	33.9	34.8	45.0	38.2	64.1
dry solids	wt%	98.76	98.37	98.39	95.25	98.14	96.61	95.87	97.67
ash of d.s.	wt%	6.53	6.51	6.53	6.44	6.56	6.57	6.73	6.82
sulphur s	wt%	6.8	6.8	6.77	6.74	6.82	6.78	6.7	6.74
calcul. SO_2-emission	ppm	3601	5177	5386	5347	5361	4769	4462	4547
"	g/MJ	4.34	4.34	4.34	4.34	4.34	4.34	4.34	4.34
Sorbent									
origin		-	Gotland						
size(50 % smaller than)	µm	-		90	75				
feeding rate	g/s	-	16.8	20.2	12.8	14.3	15.0	15.5	23.2
dry solids	%	-	99.99	99.99	99.99	99.99	99.99	99.99	99.99
$CaCO_3$ in d.s.	%	-	95.66	95.66	95.66	95.66	95.66	95.66	95.66
Ca/S-ratio	mol/mol	-	1.82	1.85	1.97	2.06	1.72	2.09	1.87
sulphur retention	%	13.5	92.6	93.7	90.6	91.5	90.2	91.5	89.7
air flow rate	g/s	364	355	399	259	277	367	262	385
Flue gases									
O_2 in dry gas	%	8.8	3.4	2.7	3.1	2.7	4.5	5.7	5.3
CO "	ppm	267	128	101	226	326	121	57	469
SO_2 "	ppm	3114	382	337	503	458	465	381	470
SO_2 "	g/MJ	3.750	0.321	0.271	0.408	0.371	0.423	0.370	0.448
NO_x "	ppm	856	304	321	296	570	682	186	166
NO_x "	g/MJ	0.741	0.183	0.186	0.172	0.331	0.446	0.130	0.114
NO_x from fuel N	ppm	1846	2656	2763	2743	2750	2446	2288	2332
NO_x "	g/MJ	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60
Coarshe ash									
mass flow	g/s	0.18	6.85	5.18	11.11	3.22[x]	6.19	10.37	2.10
carbon	wt%	0.04	0.36	0.25	2.10	3.00	4.41	0.30	0.20
S as SO_4	wt%	0.3	14.9	22.8	34.4	38.5	42.0	26.7	28.5
Ca	wt%	0.6	0.6	4.5	12.6	16.8	21.2	7.9	3.2
Baghouse ash									
dry solids	%	100	100	100	100	100	100	100	100
mass flow	g/s	2.33	8.04	15.63	3.37	2,98	5.81	6.35	11.82
carbon	wt%	14.6	8.37	7.84	9.68	7.70	4.79	7.90	7.70
S	wt%	5.6	22.5	24.0	16.6	22.5	25.5	n.a.	n.a.
Ca	wt%	0.7	0.4	5.9	6.1	6.2	1.3	n.a.	n.a.
Boiler ash									
dry solids	%	100	100	100	100	100	100	100	100
mass flow	g/s	0.26	2.72	2.93	1.55	2.86	6.38	0.78	4.86
carbon	%	12.52	6.53	3.41	9.50	8.34	2.65	3.79	3.83
S as SO_4	%								
Ca	%								
Venturiscrubber									
dry solids	mg/l								10378
water flow	l/s								1.14
carbon	%								1.35
average furnace temp.	°C	888	893	948	822	818	900	836	

x) errors in weighing

Following heat values were used:

$C + O_2 \rightarrow CO_2$	33.73 MJ/kgC
$CO + \frac{1}{2} O_2 \rightarrow CO_2$	283 MJ/mol CO

Effects of different variables on combustion efficiency were examined with regression analysis. Following variables were used:

1. Combustion efficiency was the response variable (%)
2. Average temperature in reactor (°C)
3. Superficial gas velocity in freeboard (m/s)
4. Oxygen content in wet offgas (%)
5. Primary air (per cent of total combustion air)
6. Ash taken out from baghouse (% of ash coming in baghouse)
7. Mean size of coke feed i.e. 50 wt-% passing a sieve of that size (mm)

Variables 2 - 7 were factor variables.

Analysis shows that temperature has the strongest correlation with combustion efficiency. Changing air distribution to the direction of richer secondary air increases combustion efficiency. Increasing excess air gives the same effect. Other variables have not a correlation worth mentioning with combustion efficiency.

6.4.3. Ash balance

In computer calculations it is assumed that ash of fuel and limestone is inert material. That is why ash is handled as one compound in outcoming ash flow, see computer sheets in App. 6-13. Other compounds, which have significance for material and energy balance are unburned carbon, calcium oxide and calcium sulphate.

Although division is made in bed ash and fly ash in computer printing, combination of mentioned ash compounds is considered to be as in

TABLE 5. COMBUSTION EFFICIENCIES AND LOSSES DUE TO UNBURNED MATERIAL
(Based on ash weighing)

Run No.	1	2	3	4	5	6	7	8
Fuel input kW (HHV)	1202	1404	1641	1011	1068	1360	1143	1953
coarse ash unburned C kW	0.00	0.83	0.44	7.86	3.26	9.21	1.05	3.44
boiler ash unburned C kW	1.10	5.99	3.37	4.97	8.05	5.70	1.00	6.28
baghouse ash unburned C kW	11.47	22.70	41.33	11.00	7.74	9.39	16.92	0 [2]
through baghouse [1] unburned C kW	0.74	2.63	3.31	2.74	1.25	1.57	2.45	5.38
CO in offgas kW	1.73	0.67	0.59	0.82	1.25	0.66	0.28	3.87
total losses kW	15.04	32.82	49.04	27.39	21.55 [3]	26.53	21.70	18.97 [3]
C.E. (based on HHV) %	98.75	97.66	97.01	97.29	97.98	98.05	98.10	99.03

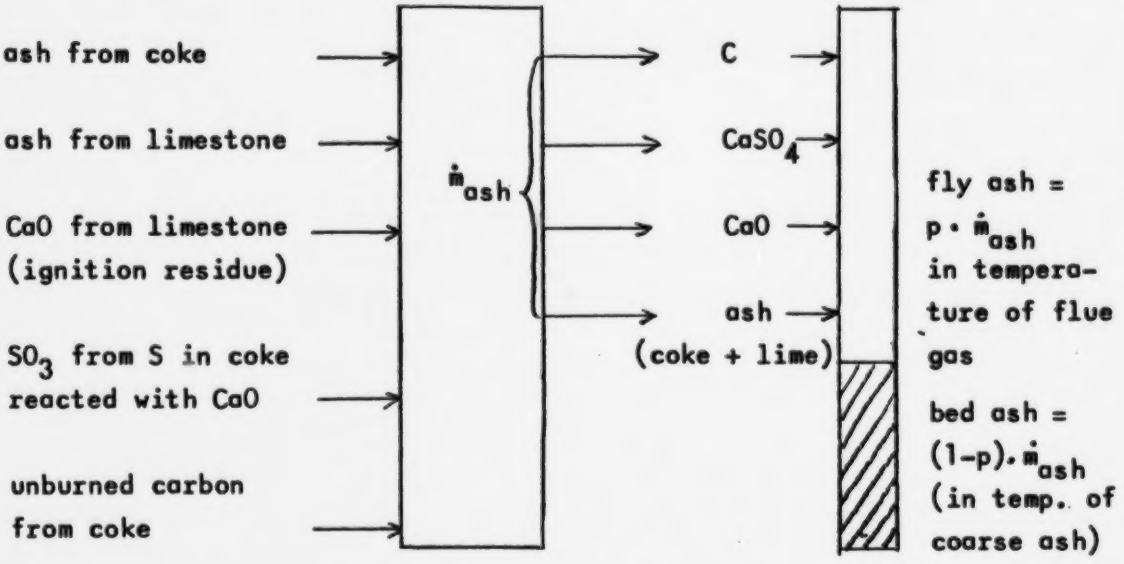
1) unburned C- % is assumed to be the same as in baghouse ash

2) baghouse bypassed

3) propable errors in ash weighing

mixed ash flow. Division is made only from basis of weighed ash amounts and it has significance merely for energy balance because of different temperatures of bed ash and fly ash.

The outcoming ash flow in computer calculations is formed following:


ash from coke
ash from limestone
CaO from limestone (ignition residue)
SO_3 from S in coke reacted with CaO
unburned carbon from coke
$\dot{m}_{ash}$
C
$CaSO_4$
CaO
ash (coke + lime)
fly ash = $p \cdot \dot{m}_{ash}$ in temperature of flue gas
bed ash = $(1-p) \cdot \dot{m}_{ash}$ (in temp. of coarse ash)

p≙ weighed ash distribution

Outcoming carbon flow is formed so that it fulfils a given percentage calculated from formula (1).

Ash distribution in trials is presented in Tab. 7. Input quantities are calculated from feed mass flows of coke and limestone with analysed properties and from theoretical formation of CaO, $CaSO_4$ and unburned carbon.

Output mass flows are average values calculated from weighing results. Division is made between coarse ash, boiler ash and baghouse ash. Weighing results in runs 1, 5 and 8 differ a lot from input massflows. Obviously the reason to difference is found from mistakes in weighing and variation bed material inventories.

In run No. 1 one can notice SO_2 absorbtion by own ash of coke, 13,5 % of total SO_2 output was removed from offgas.

Coarse ash output ranged from 6.2 % to 65.8 % of total ash. Boiler ash output depends strongly on combustion capacity and ash recirculation. With low combustion capacities without ash recirculation, it was between 9.5 % and 27 % of total fly ash. When baghouse ash was recirculated boiler ash output increased nearly to 50 % of fly ash also with minor combustion capacities, see Tab. 6 and App. 10. In maximum load run it was c. 30 %.

Table 6. Ash distribution in runs 5 and 6
(Ash recirculation from baghouse)

	Run 5	Run 6
Coarse ash g/s	5.98	6.43 (6.19)
Boiler ash g/s	5.32	6.59 (6.38)
Recirculating ash (75 % of baghouse ash) g/s	15.14	16.01
Ash out from baghouse (25 %) g/s	5.05	5.33 (5.81)
Total fly ash (Before boiler) g/s	25.51	27.921
Dust concentration before boiler g/Nm^3	74.2	56.8

- measured values in parentheses

In Tab 7 there is also dust concentration in flue gas before boiler ash removal. Ash recirculation increases dust load in flue gas duct and boiler remarkable. Same effect has increasing load.

TABLE 7. ASH DISTRIBUTION IN RUNS

Run No.		1	2	3	4	5	6	7	8
Input									
Coke ash	g/s	2.51	2.91	3.42	2.08	2.24	2.86	2.46	4.27
CaO	g/s	0	9.00	10.81	6.86	7.66	8 03	8.31	12.42
Lime ash	g/s	0	0.73	0.88	0.56	0.62	0.65	0.67	1.01
SO_3 forming $CaSO_4$	g/s	0.88	7.05	8.34	4.96	5.30	6.66	5.67	9.49
Unburned carbon	g/s	0.54	1.09	1.54	1.24	1.02	0.89	0.60	0.52
Total input	g/s	3.93	20.78	24.99	15.70	16.84	19.09	17.71	27.71
Output (weighed)									
Coarse ash	g/s	0.18	6.85	5.18	11.11	3.22	6.19	10.37	2.10
- " - of output	%	6.2	37.0	20.7	65.8	33.8	32.0	56.3	11.2
Boiler ash	g/s	0.26	2.72	2.93	1.55	2.98	6.38	0.78	4.86
- " - of output	%	8.9	14.7	11.7	9.2	31.2	33.0	4.2	25.9
Baghouse ash	g/s	2.33	8.04	15.63	3.37	2.86	5.81	6.35	-
- " - of output	%	79.9	43.3	62.6	20.0	30.0	30.0	34.5	-
Through baghouse	g/s	0.15	0.93	1.25	0.84	0.48	0.97	0.92	11.82
- " - of output	%	5	5	5	5	5	5	5	62.9
Total output	g/s	2.92	18.54	24.99	16.87	9.54	19.35	18.42	18.78
Output - Input	g/s	-1.01	-2.24	0	1.17	-7.3	0.26	0.71	-8.93
Difference of input	%	-35.6	-10.8	0	+7.5	-43.3	+1.4	+4.0	-32.2
Calculated output Total	g/s	3.93	20.78	24.98	15.69	16.83	19.09	17.71	27.70
Weighed output -									
Calc. output	g/s	-1.01	-2.24	0.01	1.18	-7.29	0.26	0.71	-8.92
Difference of calculated	%	-25.7	-10.8	+0.0	+7.5	-43.3	+1.36	+4.0	-32.2
Dust concentration before boiler (from	g/Nm^3	6.4	27.2	37.15	14.7	74.2	56.8	16.31	33.3

6.5. Emissions

6.5.1. SO_2 emission

In order to get information about the factors, which have the greatest influence on SO_2 retention, the data was analysed by multivariable regression analysis. Following variables were chosen:

1. SO_2 retention (%) was the response variable
2. Ca/S ratio (mol/mol). Calcium inherent in coke ash was not included
3. Average reactor temperature (°C)
4. Superficial gas velocity in freeboard (m/s)
5. Oxygen content in wet offgas (%)
6. Primary air of total combustion air (%)
7. Percentage of ash taken out from total ash coming to baghouse (%)
8. Size of coal feed (mm). This is size that smaller 50 wt-% of particles are.

Also the run No. 1 (without limestone) was taken into account in analysis. This gave the result that Ca/S ratio has the strongest correlation with SO_2 retention, as was expected. Particle size of coke feed seems to correlate also with retention quite well. Recirculating baghouse ash improves capture even though the effect is not as clear. Temperature seems to have rather a small influence on retention, However, if one compares the results of run 5 and 6, it is obvious that ash recirculation in higher temperatures gives better Ca-utilization.

Need of limestone was small compared with previous tests with other limestones. Gotland limestone is small in particle size and thus has large reaction surface. Its $CaCO_3$ content is also high. Small particle size of coke feed was undoubtedly one reason to good SO_2 retention. SO_2 retention figures are collected in Table 4 A1, see also App. 6-13.

6.5.2. NO_x-emission

NO_x-emission varied in large range. The highest value was 856 ppm in run 1 and the lowest one was 166 ppm in run 8, which means 0.741 $gNO_2/MJHHV$ and 0.114 $gNO_2/MJHHV$, respectively.

The data was analyzed by regression analysis in regard to NO_x-emission. The variables were:

1. NO_x-emission ($gNO_2/MJHHV$)
2. Primary air of total (%)
3. Bed temperature
4. CO-content in dry offgas (ppm)
5. Oxygen content in wet offgas (%)
6. Ash taken from baghouse (% of coming ash to baghouse)
7. Particle size of coke feed (mm)

Following results were obtained:

- Extra air has the strongest influence on NO_x-emission
- Increasing secondary air flow decreases NO_x-emission
- Ash recirculation decreases NO_x formation ?
- Temperature dependence is small which is adverse to nominally understood effect and is in contradiction to results from earlier experiments.

7. CONCLUSIONS

Eight test runs with Syncrude coke were performed in a PYROFLOW-reactor. Feeding rate of coke was 33.9 - 64.1 g/s and mean particle size 0.14 - 0.15 mm. Sulphur content varied between 6.70 % and 6.8 % and ash content between 6.44 and 6.82 %. Moisture was 1.2 - 4.7 %. There were no problems in feeding this material with the screw feeder used in trials.

Combustion efficiency was 95.8 - 98.9 %. It was noticed that combustion efficiency is a function of temperature, air distribution and extra air 7.3 - 67 %. Extra air was used corresponding to 2.5 - 8.4 % oxygen content in wet offgas. Ash recirculation from bag-house back to the furnace had not an effect worth mentioning on combustion efficiency. The best combustion efficiencies were attained on temperature level 900°C.

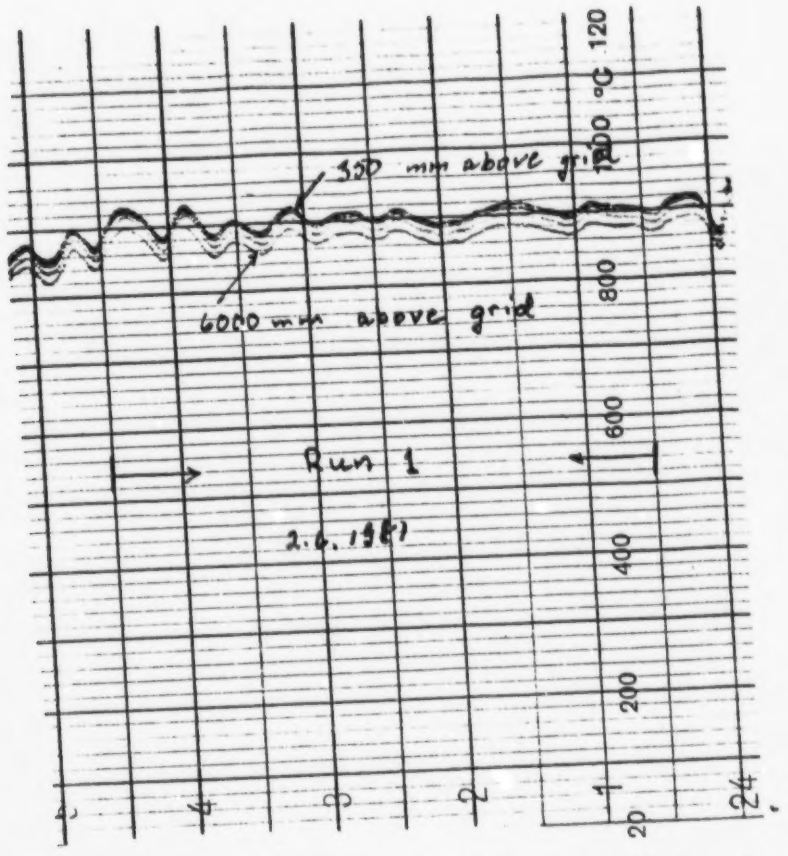
Gotland limestone was used as SO_2 sorbent. Mean particle size of limestone was 75 - 90 µm and ignition loss analysis 57.94 %. Theoretical SO_2 emission of coke was 4.34 gSO_2/MJHHV. First run was made without limestone when 13.5 % SO_2 capture was attained by own ash of coke. Emission was then 3.75 g SO_2/MJHHV. In runs with limestone SO_2 retention varied between 89.7 % and 93.7 %. SO_2-emission was in the range of 0.271 - 0.448 gSO_2/MJHHV. The above mentioned retention figures were achieved with Ca/S-ratio varying between 1.72 and 2.09 mol/mol. Ash recirculation gave the best Ca-utilization in bed temperature 900°C (Ca/S = 1.72)

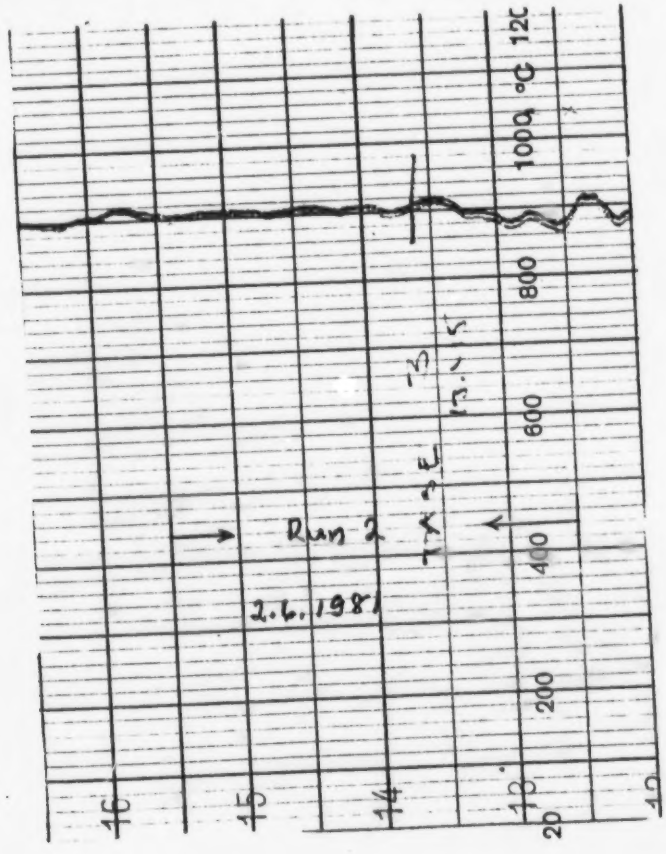
NO_x-emission varied between 0.114 gNO_2/MJHHV and 0.741 gNO_2/MJHHV. By increasing secondary air it was possible to decrease NO_x-emission onto reasonable level.

REFERENCES

(1) Thermal Power Generation Emissions - National Guidelines For New Stationary Sources, published in Canada Gazette Apr. 25, 1981

(2) ASME POWER TEST CODES, Test Code for Steam Generating Units PTC 4.1, 8 August 1972, pp. 51, 55.


320 mm above gr.
6000 mm above grid
Run 1
2.6.1981
1200 °C 120
800
600
400
200
4
2
20
24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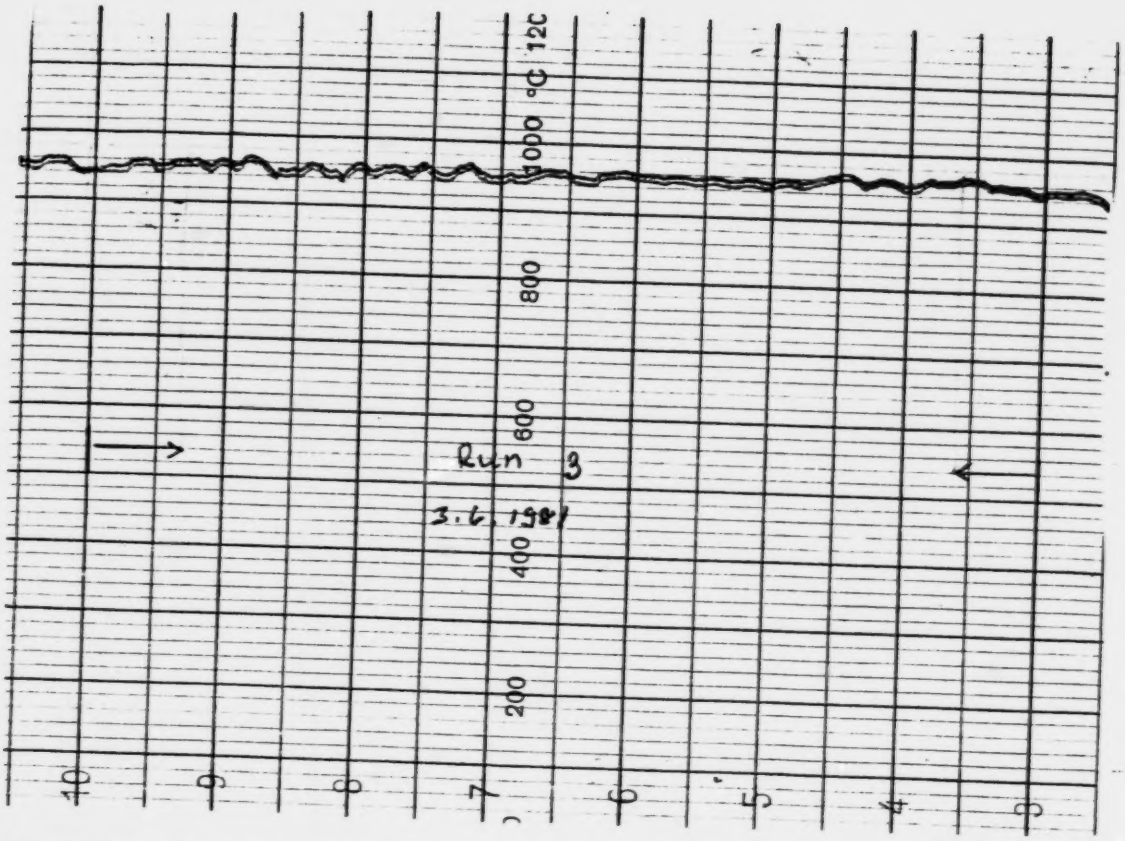
800
600
400
200
Run 2
2.6.1981
TIME
13.15
16
15
14
12
20
10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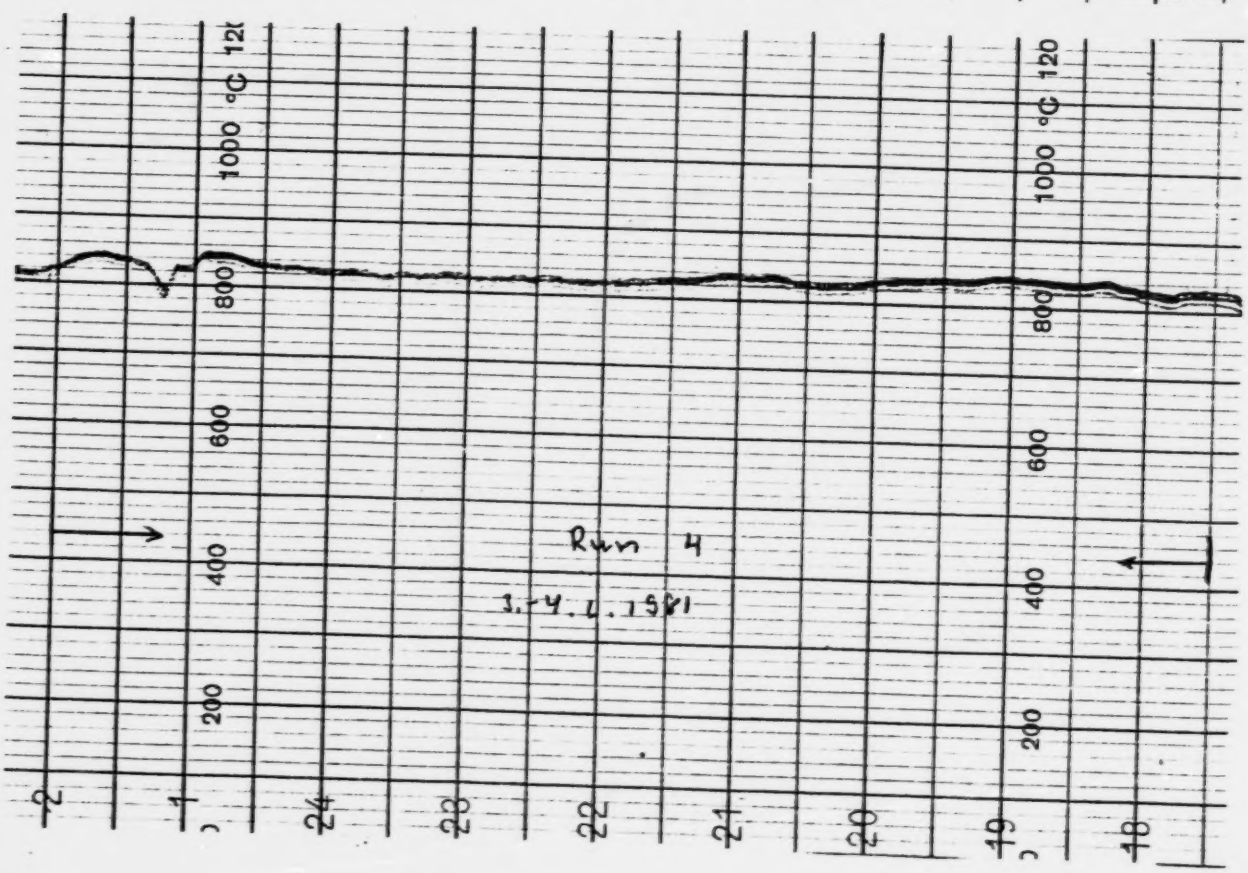
800
600
400
200
Run 3
3.6.1981
10
9
8
7
6
5
4
3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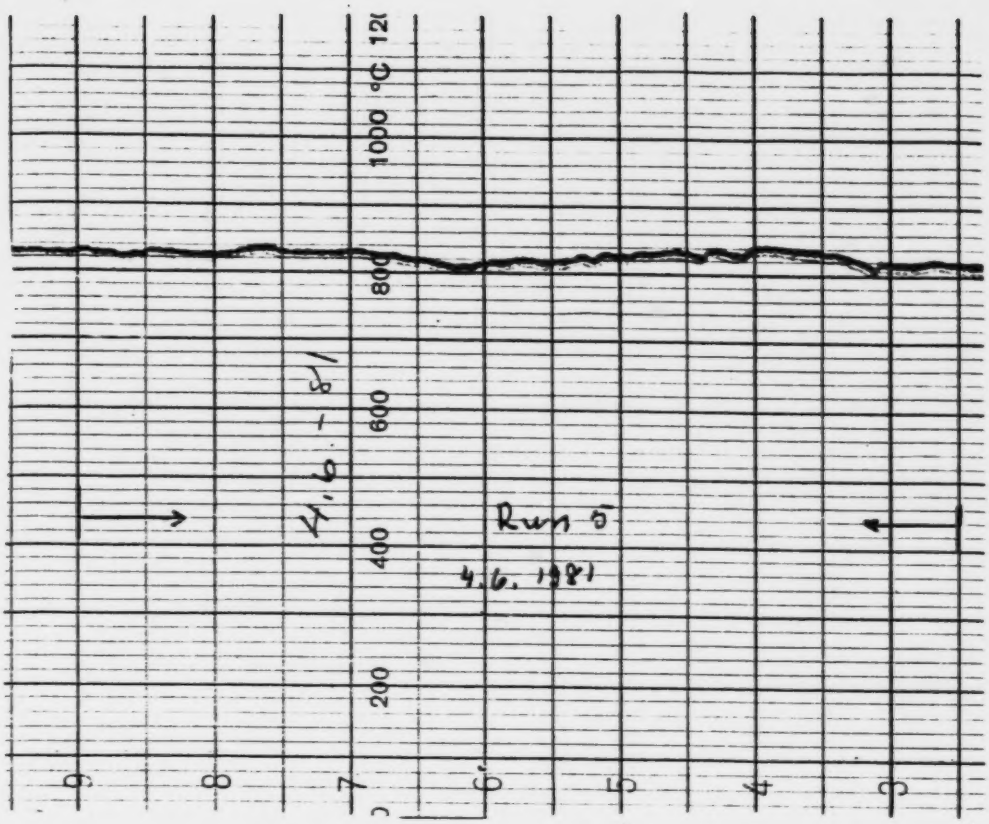
600
400
200
Run 4
3.-4.6.1981
2
1
24
23
22
21
20
19
18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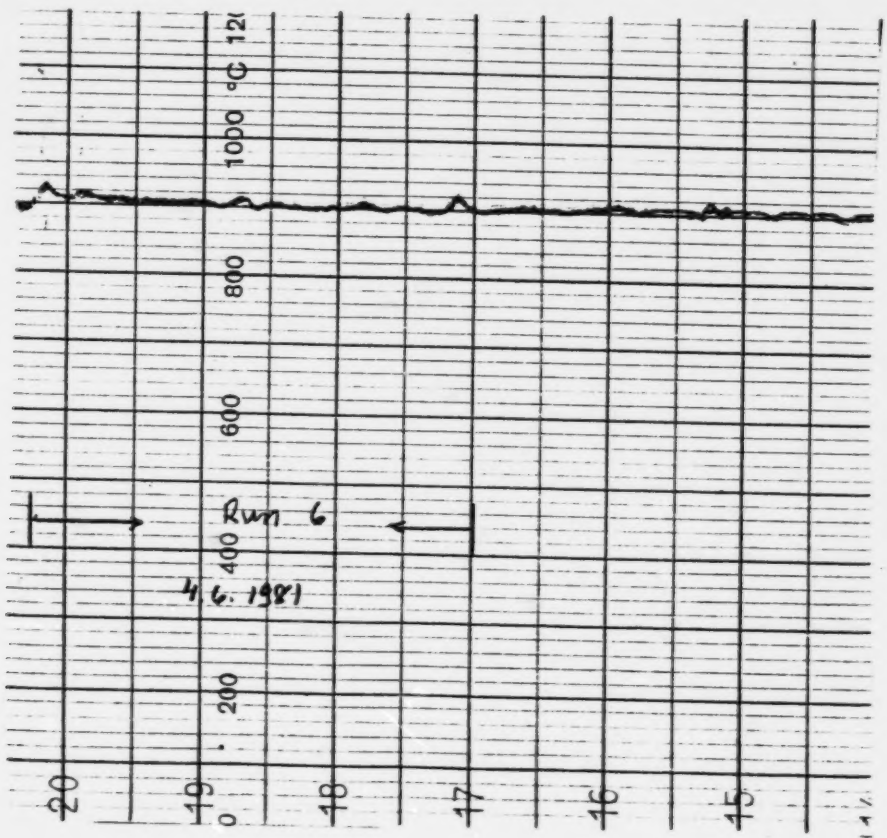
800
600
400
200
0
9
8
7
6
5
4
3
4.6. - 8/1
Run 5
4.6. 1981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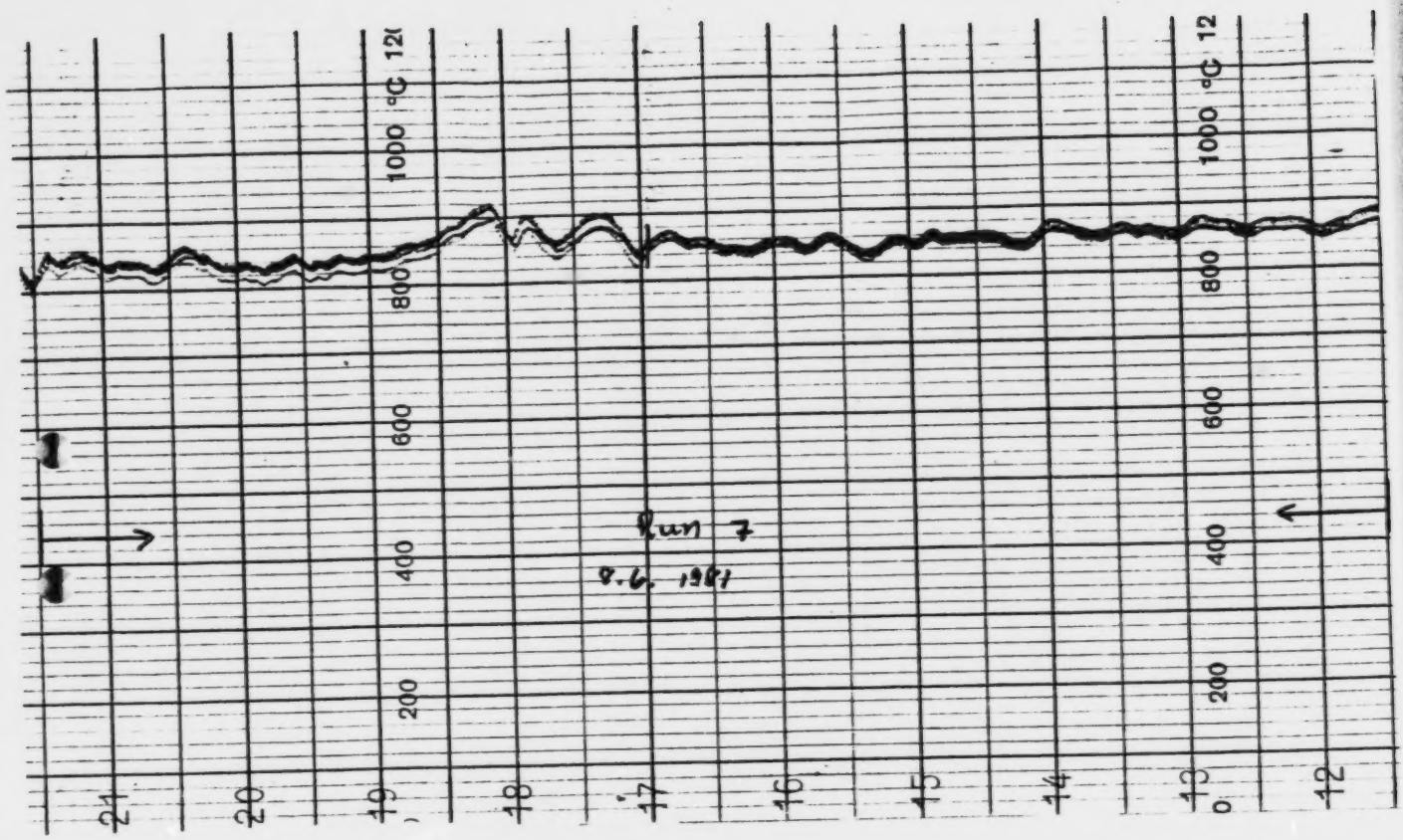
800
600
400
200
0
20
19
18
17
16
15
Run 6
4.6. 1981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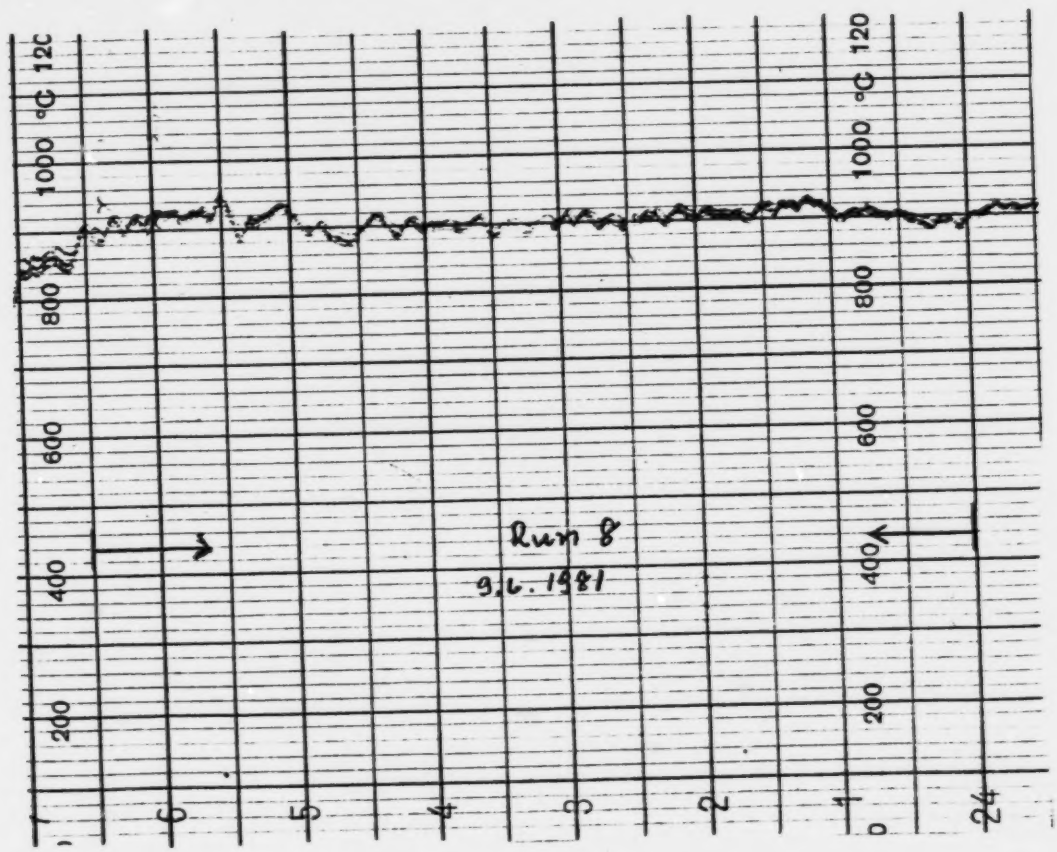
600
400
200
0
21
20
19
18
17
16
15
14
13
12
Run 7
8.6. 1981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800
600
400
200
0
6
5
4
3
2
1
24
Run 8
9.6. 1981

MATERIAL AND ENERGY BALANCE DATE: 3-6-1991 TIME: 0130:47.30 FILE: SY1:RUN1.DAT ROW NUMBER IN FILE: 8 TEST RUN: 1 TYPE: 0

COMPOSITION OF INPUT FLOWS

	N.W. G/MOL	MOIST.(S %	MOIST.(S %	COKE %	FUEL 2 %	FUEL 3* %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.514	83.667	51.190	11.477	0.000	0.000
H2	15.999	88.888	88.888	1.851	2.081	39.667	35.917	0.000	23.292
O2	1.000	11.112	11.112	1.731	1.819	5.902	0.000	0.000	0.000
N2	14.007	0.000	0.000	1.920	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	0.933	0.507	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	12.050	9.000	2.000	14.342	100.000	0.000
H2O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

* included in ash

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	0.482	20.000	0.040	0.003	0.0
MOIST.(S)	8.647	65.388	22.785	1.776	0.0
COKE	38.413	20.000	1291.570	94.762	98.8
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	0.000	20.000	0.000	0.000	100.0
REC.AS	0.000	20.000	0.000	0.000	100.0
AIR	656.492	65.388	43.615	3.439	78.7
TOTAL	704.038	0.000	1268.070	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	1.710	0.142
C	18.078	1.505
COMB. EFF.	98.353 %	(BASED ON HHV)
COMB. EFF.	98.057 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
N2	62.814	8.370	8.685	16.744	6.893	1.394
CO2	112.516	10.701	11.311	27.839	12.283	2.324
CO	0.167	0.026	0.027	0.054	0.022	0.005
H2O	15.320	3.888	0.000	46.599	19.183	3.877
O2	1.508	0.200	0.211	0.861	0.355	0.072
SO2	303.877	76.801	79.766	148.601	61.172	12.370
AR	0.890	0.113	0.000	0.226	0.093	0.019
TOTAL	700.094	100.000	100.000	242.925	100.000	20.062

	G/S	W-%	KW	%	% OF INPUT
H2O	0.501	13.650	0.012	1.327	0.001
ASH	1.102	38.190	0.362	40.080	0.030
CA	-0.346 *	-15.732	-0.147	-16.301	-0.014
SO2	0.163	63.892	0.272	74.894	0.022
TOTAL	0.259	100.000	0.903	100.000	0.075
TOTAL		99.999	0.738	100.000	0.075

FLY ASH TEMP. 150.000 C

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	257.573	267.272	0.141
SO2 (MES.)	3000.640	3113.630	3.753
SO2 (THEOR.)	3470.260	3600.940	4.340
NOX (MES.)	825.045	856.114	0.741
NOX (FUEL)	1778.740	1845.960	1.597
SO2 CAPTURE	13.333 %		
CA/S-RATIO	0.000		
AIR COEFFICIEN	1.670		
FLUE GAS M.W.	29.850	G/MOL	

APP C

TEST RUN: 2
TYPE: 0

FILE: SY1:RUN3.DAT

	M.W.				FUEL 2	FUEL 3	LIME	REC.AS	AIR
								%	
	15.011				53.669	31.190	11.472	0.000	0.000
	15.999				1.081	38.697	43.841	0.000	23.292
	1.000				1.819	1.852	0.000	0.000	0.000
	14.007				1.224	0.271	0.000	0.000	76.708
CA	40.080				0.507	0.310	0.000	0.000	0.000
	79.899				0.000	0.000	43.686	0.000	0.000
	1.008				0.000	0.000	0.000	100.000	0.000
	7.101				0.000	27838.100	19557.000	0.000	0.000

INPUT

	G/S	%		DRY BASIS %
	0.745	20.000	0.004	0.0
	7.023	9.000	1.250	0.0
	44.557	12.000	0.001	99.4
	0.000	20.000	0.000	100.0
	0.000	20.000	0.000	100.0
	16.798	23.000	0.847	100.0
	0.000	20.000	0.000	100.0
	323.225	12.000	2.000	99.0
TOTAL	402.649	20.000	100.000	

BURNED COMPOUNDS

	KW	% OF INPUT
	0.664	0.047
	36.801	2.626
COMB. EFF.	97.338	% (BASED ON HHV)
COMB. EFF.	97.092	% (BASED ON CARBON)

FLUE GASES

	G/S	VOL-% (WET)	VOL-% (DRY)	KW	%	% OF INPUT
	19.495	5.250	5.536	2.526	0.180	
	136.971	18.421	38.842	17.717	2.769	
	0.066	0.013	0.023	0.010	0.002	
	11.798	2.000	46.145	21.051	3.291	
	0.450	0.037	0.092	0.042	0.007	
	309.616	76.109	128.503	58.621	9.170	
TOL	0.256	0.029	0.070	0.032	0.005	
TOTAL	361.852	100.000	219.210	100.000	15.425	

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	122.344	127.897	0.047
SO2 (MES.)	365.843	382.448	0.321
SO2 (THEOR.)	4952.700	5177.490	4.340
NOX (MES.)	290.417	303.598	0.183
NOX (FUEL)	2540.500	2655.960	1.597
SO2 CAPTURE	72.613	%	
CA/S-RATIO	1.800		
AIR COEFFICIEN	1.151		
FLUE GAS M.W.	30.317	G/MOL	

	G/S	W-%	KW	%	% OF INPUT
	0.667	5.250	0.017	0.503	0.001
CASO4	1.323	57.669	2.037	59.464	0.145
CAO	0.179	19.521	0.678	19.782	0.048
CAS	0.230	17.560	0.694	20.250	0.049
TOTAL	12.673	100.000	3.425	100.000	0.244
TOTAL ASH	13.782	100.000	4.141	100.000	0.313

	G/S	W-%	KW	%	% OF INPUT
	0.424	5.250	0.005	0.488	0.000
CASO4	1.662	57.669	0.573	59.266	0.041
CAO	1.578	19.521	0.198	20.539	0.014
CAS	1.420	17.560	0.190	19.707	0.014
TOTAL	0.084	100.000	0.966	100.000	0.069

BED ASH TEMP. 150.000 C

App. 3

...LANCE

DATE: - 3-4-1991
TIME: 9:11:10:A

FILE:
ROW NUMBER IN FILE: SY1:RUN4.DAT

TEST RUN: 3
TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(I %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	[illegible]	81.516	83.669	51.190	11.478	0.000	0.000
H	15.999	88.888	88.[illegible]	1.851	1.081	39.667	45.917	0.000	23.292
S	1.000	11.112	11.[illegible]	1.791	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	[illegible]	1.[illegible]	1.924	0.231	0.000	0.000	76.708
CA	40.080	0.000	[illegible]	[illegible]	0.507	0.010	0.000	0.000	0.000
ASH	1.000	0.000	[illegible]	[illegible]	0.000	0.000	32.604	0.000	0.000
HHV	0.000	0.000	0.00	31270.[illegible]	32889.100	19833.[illegible]	891.[illegible]	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	0.860	20.000	0.[illegible]	0.004	0.0
MOIST.(I)	7.893	60.280	20.[illegible]	1.210	0.0
COKE	32.442	20.000	1640.[illegible]	85.818	98.4
FUEL 2	0.000	20.000	0.[illegible]	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	20.168	20.000	14.[illegible]	0.832	100.0
REC.ASH	0.000	20.000	0.000	0.000	100.0
AIR	599.240	60.280	36.[illegible]	2.137	98.7
TOTAL	680.603	0.000	1712.[illegible]	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	0.592	0.036
C	52.071	3.175
COMB. EFF.	96.789 %	(BASED ON HHV)
COMB. EFF.	96.519 %	(BASED ON CARBON)

OUTPUT

FLUE GASES

	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
N2	17.875	2.[illegible]	2.702	4.847	2.032	0.286
CO2	137.368	16.777	17.[illegible]	43.057	18.036	2.[illegible]
CO	0.059	0.010	0.010	0.019	0.008	0.001
H2O	17.204	4.[illegible]	0.000	52.492	21.[illegible]	3.[illegible]
[illegible]	0.445	0.[illegible]	0.074	0.087	0.036	0.[illegible]
SO2	460.353	[illegible]	77.662	138.114	57.8[illegible]	8.[illegible]
O2	0.304	0.031	0.032	0.079	0.033	0.[illegible]
TOTAL	633.607	100.000	100.000	238.696	100.000	14.[illegible]

FLY ASH

	G/S	W-%	KW	%	% OF INPUT
C	1.207	6.180	0.030	0.597	0.002
CaSO4	11.089	56.765	2.922	59.046	0.178
CaO	3.876	19.842	1.007	20.352	0.061
ASH	3.362	17.213	0.990	20.005	0.060
TOTAL	19.534	100.000	4.948	100.000	0.302
TOTAL ASH	24.280	100.000	5.593	100.000	0.341

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	96.929	101.420	0.036
SO2 (MES.)	321.764	336.672	0.271
SO2 (THEOR.)	5147.240	5385.720	4.340
NOX (MES.)	306.456	320.655	0.186
NOX (FUEL)	2640.420	2762.910	1.597
SO2 CAPTURE	93.749 %		
CA/S-RATIO	1.849		
AIR COEFFICIEN	1.109		
FLUE GAS M.W.	30.373	G/MOL	

BED ASH	G/S	W-%	KW	%	% OF INPUT
C	0.337	6.180	0.004	0.579	0.000
CaSO4	3.091	56.765	0.380	58.864	0.023
CaO	1.081	19.842	0.136	21.065	0.008
ASH	0.937	17.213	0.126	19.492	0.008
TOTAL	5.446	100.000	0.645	100.000	0.039

BED ASH TEMP. 150.000 C

App. 8

MATERIAL AND ENERGY BALANCE DATE: 3-14-1981 FILE: SY1:RUN7.DAT TEST RUN: 4
TIME: 1:08-2:05 ROW NUMBER IN FILE: 0 TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.595	83.669	51.190	11.479	0.000	0.000
O	15.999	88.888	88.888	1.852	2.081	39.667	48.717	0.000	23.292
H	1.000	11.112	11.112	1.792	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.322	1.924	0.031	0.000	0.000	76.708
S	32.060	0.000	0.000	6.799	7.507	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	6.440	3.000	3.000	1.340	100.000	0.000
HHV	0.000	0.000	0.000	31300.100	22888.100	19853.700	541.428	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	1.612	20.000	0.133	0.013	0.0
MOIST.(G)	4.095	67.556	12.945	1.224	0.0
COKE	32.290	20.000	1011.210	95.600	95.3
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	12.799	20.000	7.123	0.673	100.0
REC.ASH	0.000	20.000	0.000	0.000	100.0
AIR	371.728	57.958	26.343	2.490	98.7
TOTAL	423.324	0.000	1057.750	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	0.819	0.081
C	41.703	4.126
COMB. EFF.	95.793 %	(BASED ON HHV)
COMB. EFF.	95.430 %	(BASED ON CARBON)

OUTPUT

FLUE GASES

	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
O2	12.406	2.881	3.023	3.083	2.186	0.305
CO2	97.262	16.121	17.238	23.950	16.983	2.370
CO	0.081	0.022	0.023	0.024	0.017	0.002
H2O	11.716	1.937	0.000	35.212	24.969	3.484
SO2	0.413	0.048	0.050	0.073	0.052	0.007
N2	285.573	75.760	79.611	78.641	55.764	7.781
MG2	0.174	0.028	0.030	0.041	0.029	0.004
TOTAL	407.624	100.000	100.000	141.025	100.000	13.954

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	215.121	226.056	0.080
SO2 (MES.)	478.665	502.997	0.408
SO2 (THEOR.)	5088.730	5347.400	4.340
NOX (MES.)	281.207	295.502	0.172
NOX (FUEL)	2610.400	2743.250	1.597
SO2 CAPTURE	90.594 %		
CA/S-RATIO	1.970		
AIR COEFFICIEN	1.117		
FLUE GAS M.W.	30.293	G/MOL	

FLY ASH

	G/S	W-%	KW	%	% OF INPUT
C	0.380	7.880	0.008	0.771	0.001
CASO4	2.593	53.826	0.616	56.892	0.061
CAO	1.036	21.501	0.244	22.547	0.024
ASH	0.809	16.794	0.214	19.791	0.021
TOTAL	4.817	100.000	1.083	100.000	0.107

BED ASH

	G/S	W-%	KW	%	% OF INPUT
C	0.857	7.880	0.010	0.751	0.001
CASO4	5.853	53.826	0.719	56.725	0.071
CAO	2.338	21.501	0.294	23.198	0.029
ASH	1.826	16.794	0.245	19.327	0.024
TOTAL	10.873	100.000	1.267	100.000	0.125

TOTAL ASH 15.690 100.000 2.350 100.000 0.232 BED ASH TEMP. 150.000 C

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MATERIAL AND ENERGY BALANCE

DATE: -4.6.1991
TIME: 2:30-9:00

FILE: SY1:RUN8.DAT
ROW NUMBER IN FILE: 0

TEST RUN: 5
TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.490	83.669	51.190	11.479	7.700	0.000
O	15.999	88.888	88.888	1.850	2.081	39.667	45.917	15.000	23.292
H	1.000	11.112	11.112	1.790	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.520	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.790	7.507	0.010	0.000	7.500	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	6.200	0.000
ASH	1.000	0.000	0.000	6.560	3.000	3.000	4.340	63.600	0.000
HHV	0.000	0.000	0.000	31260.000	22888.100	19853.700	~~17580.460~~ 439	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	0.649	20.000	0.054	0.005	0.0
MOIST.(G)	5.154	69.024	13.619	1.176	0.0
COKE	34.153	20.000	1068.180	92.270	98.1
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	14.299	20.000	~~48.331~~ 16.5	4.166	100.0
REC.ASH	13.142	~~30.000~~ 158	~~0.225~~ 2.16	0.019	100.0
AIR	391.329	69.024	27.361	2.363	98.7
TOTAL	460.723	0.000	~~1153.770~~ 1117.9	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	1.246	0.117
C	33.238	3.113
COMB. EFF.	96.770 %	(BASED ON HHV)
COMB. EFF.	93.631 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
N2	11.356	2.514	2.631	3.077	1.970	0.288
	105.109	16.910	17.703	28.365	18.157	2.657
	0.123	0.031	0.032	0.040	0.026	0.004
	11.305	3.442	0.000	34.486	22.076	3.230
SO2	0.396	0.044	0.046	0.077	0.049	0.007	
	330.581	75.994	79.332	90.083	57.664	8.438
	0.354	0.054	0.057	0.091	0.058	0.009
TOTAL	459.223	100.000	100.000	156.220	100.000	14.633

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	311.829	326.346	0.116
SO2 (MES.)	437.844	458.227	0.371
SO2 (THEOR.)	5122.810	5361.290	4.340
NOX (MES.)	544.286	569.624	0.331
NOX (FUEL)	2627.560	2750.010	1.597
SO2 CAPTURE	91.453 %		
CA/S-RATIO	2.064		
AIR COEFFICIEN	1.073		
FLUE GAS M.W.	30.399	G/MOL	

	G/S	W-%	KW	%	% OF INPUT
	0.360	6.030	0.004	0.554	0.000
	2.624	43.914	0.322	44.622	0.030
	0.621	10.396	0.078	10.815	0.007
	2.370	39.661	0.318	44.010	0.030
TOTAL	5.975	100.000	0.722	100.000	0.068

	G/S	W-%	KW	%	% OF INPUT
	1.538	4.030	0.038	0.365	0.004
	11.102	43.914	2.948	44.340	0.276
	0.652	10.396	0.688	10.351	0.064
	2.370	39.661	2.971	44.743	0.279
TOTAL	37.762	100.000	6.645	100.000	0.623

FLY ASH 31.481 100.000 7.376 100.000 0.690

BED ASH TEMP. 150.000 C

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MATERIAL AND ENERGY BALANCE DATE: 4.6.1981 TIME: 2:30-9:00 FILE: SY1:RUN8.DAT ROW NUMBER IN FILE: 0 TEST RUN: 5 TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.490	83.669	51.190	11.479	0.000	0.000
O	15.999	88.888	88.888	1.850	2.081	39.667	45.917	0.000	23.292
H	1.000	11.112	11.112	1.790	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.520	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.790	7.507	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	6.560	3.000	3.000	4.340	100.000	0.000
MW	0.000	0.000	0.000	31260.000	22888.100	19853.700	438.945	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	0.649	20.000	0.054	0.005	0.0
MOIST.(G)	5.118	67.024	13.523	1.212	0.0
COKE	34.153	80.000	1048.189	93.765	98.1
FUEL 2	0.000	80.000	0.000	0.000	100.0
FUEL 3	0.000	80.000	0.000	0.000	100.0
LIME	14.287	80.000	6.487	0.582	100.0
REC.AS	0.000	80.000	0.000	0.000	100.0
AIR	389.090	80.000	27.196	2.436	98.1
TOTAL	442.800	0.000	1115.110	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	1.237	0.116
C	34.233	3.206
COMB. EFF.	96.678 %	(BASED ON HHV)
COMB. EFF.	96.378 %	(BASED ON CARBON)

OUTPUT

	G/S	W-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
N2	311.273	2.914	2.631	3.055	1.969	0.286
O2	104.078	18.822	17.661	28.086	18.099	2.631
AR	0.122	0.011	0.007	0.040	0.026	0.004
CO2	11.269	6.167	0.000	34.376	22.152	3.220
H2O	0.372	0.034	0.046	0.076	0.049	0.007
ASH	238.481	73.019	79.872	89.454	57.646	8.379
MISC	0.351	0.054	0.037	0.091	0.058	0.008
TOTAL	442.867	100.000	100.000	155.179	100.000	14.535

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	311.769	326.346	0.115
SO2 (MES.)	437.760	458.227	0.368
SO2 (THEOR.)	5160.500	5401.780	4.340
NOX (MES.)	544.181	569.624	0.329
NOX (FUEL)	2646.720	2770.810	1.597
SO2 CAPTURE	91.517 %		
CA/S-RATIO	2.062		
AIR COEFFICIEN	1.104		
FLUE GAS M.W.	30.390	G/MOL	

FLY ASH	G/S	W-%	KW	%	% OF INPUT
C	0.655	6.030	0.016	0.582	0.001
CASO4	6.013	53.544	1.329	55.660	0.143
CAO	2.543	23.427	0.660	24.016	0.062
ASH	1.845	16.998	0.343	19.743	0.051
TOTAL	10.856	100.000	2.348	100.000	0.257
TOTAL ASH	12.831	100.000	3.452	100.000	0.324

BED ASH	G/S	W-%	KW	%	% OF INPUT
CASO4	0.360	6.030	0.004	0.564	0.000
CAO	3.199	53.544	0.393	55.408	0.037
ASH	1.400	23.427	0.176	24.819	0.016
C	1.015	16.998	0.136	19.209	0.013
TOTAL	5.975	100.000	0.709	100.000	0.066

BED ASH TEMP. 150.000 C

App. 10.1

MATERIAL AND ENERGY BALANCE

DATE: - 4.6.1981
TIME: 17:00-20:15

FILE:
ROW NUMBER IN FILE: 0

TEST RUN: 6
TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.481	83.669	51.190	11.479	7.700	0.000
O	15.999	88.888	88.888	1.850	2.081	39.667	45.917	15.000	23.292
H	1.000	11.112	11.112	1.790	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.520	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.789	7.507	0.010	0.000	7.500	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	6.200	0.000
ASH	1.000	0.000	0.000	6.570	3.000	3.000	4.340	63.600	0.000
HHV	0.000	0.000	0.000	31256.700	22888.100	19853.700	3799.640	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	1.527	20.000	0.128	0.009	0.0
MOIST.(G)	7.384	65.000	19.447	1.318	0.0
COKE	43.475	20.000	1359.580	92.138	96.6
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	14.999	20.000	~~57.207~~ 13.3	3.877	100.0
REC.ASH	16.006	160.000	2.318	0.157	100.0
AIR	560.615	65.000	36.911	2.501	98.7
TOTAL	644.004	0.000	~~1475.800~~ 1431.7	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	0.661	0.049
C	28.840	2.122
COMB. EFF.	97.829 %	(BASED ON HHV)
COMB. EFF.	95.756 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
O2	27.328	4.230	4.424	8.645	3.432	0.636
CO2	134.649	15.154	15.848	42.820	17.001	3.151
CO	0.065	0.012	0.012	0.025	0.010	0.002
H2O	15.913	4.379	0.000	49.996	19.850	3.679
SO2	0.575	0.044	0.047	0.131	0.052	0.010
N2	430.498	76.116	79.602	150.065	59.581	11.043
NO2	0.606	0.065	0.068	0.184	0.073	0.014
TOTAL	609.633	100.000	100.000	251.866	100.000	18.535

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	115.701	121.000	0.048
SO2 (MES.)	444.638	465.000	0.423
SO2 (THEOR.)	4559.930	4768.750	4.340
NOX (MES.)	652.135	682.000	0.446
NOX (FUEL)	2338.390	2445.570	1.597
SO2 CAPTURE	90.249 %		
CA/S-RATIO	1.723		
AIR COEFFICIEN	1.214		
FLUE GAS M.W.	30.195	G/MOL	

FLY ASH	G/S	W-%	KW	%	% OF INPUT	BED ASH	G/S	W-%	KW	%	% OF INPUT
C	1.301	4.660	0.038	0.433	0.003	C	0.300	4.660	0.003	0.423	0.000
CASO4	13.336	47.763	4.220	47.588	0.311	CASO4	3.072	47.763	0.377	47.949	0.028
CAO	2.161	7.741	0.667	7.517	0.049	CAO	0.498	7.741	0.063	7.956	0.005
ASH	11.123	39.836	3.943	44.463	0.290	ASH	2.562	39.836	0.344	43.673	0.025
TOTAL	27.921	100.000	8.868	100.000	0.653	TOTAL	6.432	100.000	0.787	100.000	0.058
TOTAL ASH	34.354	100.000	9.655	100.000	0.711	BED ASH TEMP.	150.000 C				

App. 11

MATERIAL AND ENERGY BALANCE

DATE: 4.6.1981
TIME: 19:00-20:15

FILE:
ROW NUMBER IN FILE: 0

TEST RUN: 6
TYPE: 8

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.481	83.669	51.190	11.479	0.000	0.000
O	15.999	88.888	88.888	1.850	2.081	39.667	45.917	0.000	23.292
H	1.000	11.112	11.112	1.790	1.819	5.802	0.000	0.000	0.000
N	14.007	0.000	0.000	1.520	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.789	7.307	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	6.570	3.000	3.000	4.340	100.000	0.000
HHV	0.000	0.000	0.000	31256.700	22888.100	19853.700	872.404	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	1.527	20.000	0.128	0.009	0.0
MOIST.(G)	7.299	65.000	19.225	1.346	0.0
COKE	43.475	20.000	1359.580	95.160	96.6
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	14.999	20.000	13.305	0.931	100.0
REC.ASH	0.000	20.000	0.000	0.000	100.0
AIR	554.174	65.000	36.457	2.554	98.7
TOTAL	621.473	0.000	1428.720	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	0.653	0.048
C	30.002	2.208
COMB. EFF.	97.744 %	(BASED ON HHV)
COMB. EFF.	97.531 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
CO2	27.010	1.230	4.425	8.545	3.429	0.629
SO2	132.742	15.113	15.812	42.213	16.942	3.107
SO3	0.065	0.012	0.012	0.025	0.010	0.002
O2	15.829	4.407	0.000	49.731	19.959	3.660
H2O	0.568	0.044	0.047	0.130	0.052	0.010
N2	425.559	76.127	79.637	148.344	59.535	10.917
HCl	0.599	0.065	0.068	0.182	0.073	0.013
TOTAL	602.371	100.000	100.000	249.169	100.000	18.337

FLY ASH	G/S	W-%	KW	%	% OF INPUT
C	0.590	4.660	0.017	0.446	0.001
CASO4	7.509	59.339	2.376	60.838	0.175
CAO	2.231	17.627	0.688	17.613	0.051
ASH	2.325	18.375	0.824	21.104	0.061
TOTAL	12.655	100.000	3.906	100.000	0.287
TOTAL ASH	19.087	100.000	4.679	100.000	0.344

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	115.668	121.000	0.048
SO2 (MES.)	444.508	465.000	0.418
SO2 (THEOR.)	4613.520	4826.210	4.340
NOX (MES.)	651.945	682.000	0.440
NOX (FUEL)	2365.900	2475.070	1.597
SO2 CAPTURE	90.365 %		
CA/S-RATIO	1.721		
AIR COEFFICIEN	1.236		
FLUE GAS M.W.	30.186	G/MOL	

BED ASH	G/S	W-%	KW	%	% OF INPUT
C	0.300	4.660	0.003	0.430	0.000
CASO4	3.817	59.339	0.469	60.629	0.034
CAO	1.134	17.627	0.143	18.438	0.010
ASH	1.182	18.375	0.159	20.502	0.012
TOTAL	6.432	100.000	0.773	100.000	0.057

BED ASH TEMP. 150.000 C

App 11.1

MATERIAL AND ENERGY BALANCE

DATE: 8.6.1981
TIME: 13:33-21:30

FILE: SY1:RUN2.DAT
ROW NUMBER IN FILE: 8

TEST RUN: 7
TYPE: 6

COMPOSITION OF INPUT FLOWS

	N.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.342	83.669	51.170	11.479	0.000	0.000
O	15.999	88.888	88.888	1.847	2.081	39.667	45.917	0.000	23.292
H	1.000	11.112	11.112	1.787	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.517	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.778	7.507	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	6.730	3.000	3.000	4.340	100.000	0.000
HHV	0.000	0.000	0.000	31203.100	22888.100	19853.700	410.325	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	1.379	20.000	0.132	0.011	0.0
MOIST.(G)	6.525	66.529	17.470	1.454	0.0
COKE	36.422	20.000	1143.340	95.163	95.9
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	10.478	20.000	6.550	0.549	100.0
REC.ASH	0.000	20.000	0.000	0.000	100.0
AIR	302.989	66.529	33.838	2.821	98.1
TOTAL	363.314	0.000	1201.130	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	0.280	0.025
C	20.368	1.782
COMB. EFF.	98.193 %	(BASED ON HHV)
COMB. EFF.	98.050 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
	31.158	3.269	3.410	9.597	4.361	0.840
	113.412	11.896	14.054	35.057	15.932	3.068
	0.029	0.003	0.004	0.010	0.005	0.001
	14.093	1.479	0.000	44.041	20.018	3.855
	0.423	0.044	0.058	0.094	0.043	0.008
	396.389	73.044	77.175	131.202	59.628	11.482
	0.148	0.013	0.017	0.044	0.020	0.004
TOTAL	545.392	100.000	100.000	220.045	100.000	19.256

FLY ASH	G/S	W-%	KW	%	% OF INPUT
	0.246	3.410	0.007	0.323	0.001
	3.924	54.444	1.203	55.295	0.105
	1.761	24.430	0.506	24.233	0.044
	1.277	17.716	0.458	20.150	0.039
	7.207	100.000	2.173	100.000	0.190
	7.207	100.000	2.173	100.000	0.302

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	54.591	57.054	0.024
SO2 (MES.)	364.091	380.520	0.370
SO2 (THEOR.)	4269.020	4461.640	4.340
NOX (MES.)	177.932	185.961	0.130
NOX (FUEL)	2189.560	2288.460	1.597
SO2 CAPTURE	91.471 %		
CA/S-RATIO	2.089		
AIR COEFFICIEN	1.337		
FLUE GAS M.W.	30.084	G/MOL	

BED ASH

	G/S	W-%	KW	%	% OF INPUT
C	0.358	3.410	0.004	0.311	0.000
	5.717	54.444	0.702	54.933	0.061
	2.563	24.430	0.323	25.235	0.028
ASH	1.860	17.716	0.249	19.521	0.022
TOTAL	10.501	100.000	1.278	100.000	0.112

BED ASH TEMP. 150.000 C

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MATERIAL AND ENERGY BALANCE DATE: -7.6.1991 TIME: 0:00-6:29 FILE: SY1:RUN5.DAT ROW NUMBER IN FILE: 0 TEST RUN: 8 TYPE: 0

COMPOSITION OF INPUT FLOWS

	M.W. G/MOL	MOIST.(S %	MOIST.(G %	COKE %	FUEL 2 %	FUEL 3 %	LIME %	REC.AS %	AIR %
C	12.011	0.000	0.000	81.263	83.669	51.190	11.479	0.000	0.000
O	15.999	88.888	88.886	1.845	2.081	39.667	45.917	0.000	23.292
H	1.000	11.112	11.112	1.785	1.819	5.902	0.000	0.000	0.000
N	14.007	0.000	0.000	1.516	1.924	0.231	0.000	0.000	76.708
S	32.060	0.000	0.000	6.771	7.507	0.010	0.000	0.000	0.000
CA	40.080	0.000	0.000	0.000	0.000	0.000	38.264	0.000	0.000
ASH	1.000	0.000	0.000	6.820	3.000	3.000	4.340	100.000	0.000
HHV	0.000	0.000	0.000	31173.000	22888.100	19853.700	666.585	0.000	0.000

INPUT

	G/S	C	KW	%	DRY MAT. (%)
MOIST.(S)	1.496	20.000	0.125	0.006	0.0
MOIST.(G)	11.111	55.991	29.061	1.421	0.0
COKE	62.607	20.000	1952.670	95.462	97.7
FUEL 2	0.000	20.000	0.000	0.000	100.0
FUEL 3	0.000	20.000	0.000	0.000	100.0
LIME	23.198	20.000	15.804	0.773	100.0
REC.ASH	0.000	20.000	0.000	0.000	100.0
AIR	843.600	55.991	47.842	2.339	98.7
TOTAL	942.011	0.000	2045.500	100.000	

UNBURNED COMPOUNDS

	KW	% OF INPUT
CO	3.857	0.198
C	17.381	0.891
COMB. EFF.	98.912 %	(BASED ON HHV)
COMB. EFF.	98.732 %	(BASED ON CARBON)

OUTPUT

FLUE GASES	G/S	MOL-% (WET)	MOL-% (DRY)	KW	%	% OF INPUT
O2	48.493	4.995	5.212	15.923	4.121	0.816
CO2	193.682	14.506	15.134	64.081	16.583	3.283
CO	0.382	0.045	0.047	0.151	0.039	0.008
H2O	22.664	4.150	0.000	71.754	18.569	3.677
SO2	0.875	0.045	0.047	0.208	0.054	0.011
N2	647.967	76.242	79.544	234.233	60.616	12.002
NO2	0.222	0.016	0.017	0.070	0.018	0.004
TOTAL	914.284	100.000	100.000	386.419	100.000	19.800

EMISSION FIGURES

	MOL-PPM (WET)	MOL-PPM (DRY)	G/MJ
CO (MES.)	449.232	468.685	0.196
SO2 (MES.)	450.100	469.590	0.448
SO2 (THEOR.)	4358.310	4547.040	4.340
NOX (MES.)	158.793	165.669	0.114
NOX (FUEL)	2235.430	2332.330	1.597
SO2 CAPTURE	89.673 %		
CA/S-RATIO	1.868		
AIR COEFFICIEN	1.314		
FLUE GAS M.W.	30.136	G/MOL	

FLY ASH	G/S	W-%	KW	%	% OF INPUT
C	0.458	1.860	0.014	0.174	0.001
CASO4	14.334	58.266	4.744	58.254	0.243
CAO	5.124	20.829	1.648	20.233	0.084
ASH	4.686	19.046	1.738	21.339	0.089
TOTAL	24.602	100.000	8.144	100.000	0.417
TOTAL ASH	23.304	100.000	8.522	100.000	0.437

BED ASH	G/S	W-%	KW	%	% OF INPUT
C	0.058	1.860	0.001	0.167	0.000
CASO4	1.808	58.266	0.222	57.943	0.011
CAO	0.646	20.829	0.081	21.206	0.004
ASH	0.591	19.046	0.079	20.684	0.004
TOTAL	3.103	100.000	0.383	100.000	0.020

BED ASH TEMP. 150.000 C

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POOR

QUALITY

ORIGINAL